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APPLICATION OF ELECTRON BEAM WELDING TO HEAVY COMPONENTS

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June 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The current investigation evaluates the mechanical properties and weld soundness of an electron beam welded casting which was substituted for a complex forging. The mechanical properties obtained were adequate, however, radiographic studies indicated considerable porosity in the welds which was not tolerable. This porosity was the result of the agglomeration of porosity on forged specimens of the same alloy and configuration. The study showed

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that weldments made from forged sub-sections could meet the mechanical property and soundness requirements.

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BENET WEAPONS LABORATORY, LCWSL
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DRDAR-LCB-SE

Project No: 6747480

Project Title: Application of Electron Beam Welding to Heavy Components

Statement of the Problem: Electron beam welding has long been applied to thin sections with excellent results. However, there has been a considerable lack of experience in the welding of thick sections. If castings and forged sections up to 1-1/2 inches thick could be welded together to form complete assemblies with no loss in mechanical properties, difficult components could be fabricated on a broader production base.

Background and Introduction: The purpose of this welding development was to determine the feasibility of fabricating Muzzle Brakes by joining appropriate smaller sub-sections, produced by forging or casting, into a complete assembly with the Electron Beam welding process.

Object and Procedure: The basic object of this project is to generate the welding process parameters required to achieve sound welds in thick forged and cast components in order to develop specifications which will permit electron beam fabrication techniques and reduce the cost of components while increasing the production base. The scope of the project also included the design of prototype tooling to weld the muzzle brakes on a production basis.

a. Test Samples

The cast sections, as received for evaluation, consisted of details which, when appropriately sectioned, machined and assembled, would produce two complete muzzle brake assemblies. In addition, forged test pieces were supplied sections which were machined to simulate the thicknesses and configurations of the weldment in the weld joint areas (Figures 1 and 2).

This project was accomplished as part of the US Army Manufacturing Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in production of Army materiel.

The variation in thickness of the test assemblies from approximately 1/2 inch at the ends to 1 inch, and 1-1/8 inch at the center respectively, determined that a variable power-input to the weld would be required to produce adequate and consistent full penetration through the weld joint over the entire length of the weld.

A preliminary weld schedule was established for each of the extremes of thickness in each of the two parts to be welded, maintaining a constant accelerating voltage, focus and speed, varying only the beam current. Using the combined parameters of the two weld schedules, test welds were performed on solid tapered thickness plates to develop the necessary timing skills which would be required by the welding operator with respect to beam current/thickness correlation. The skill was developed without great difficulty.

Using the established weld schedules and operating techniques, one each of the required test assemblies was welded, primarily to determine whether modification of the schedule would be required as a consequence of variations of the weld joint as opposed to solid plate. Visual inspection of the welds showed that penetration was adequate without being excessive, and it was decided that schedule variation would not be required.

The test welds were non-destructively tested in the as-welded condition by the magnetic particle and radiographic processes. Magnetic particle examination showed no defects in any weld. Radiographic inspection showed that both test pieces contained indications in the joint welds, but that test welds made on the base material of the test material were sound. Since one test component was nearly perfect, containing a single indication only 1/2 inch in length, it was determined that an unknown had been present in the welding of the second of the two test pieces and that the test should be repeated under closer controls. Typical sections of these welds are shown in Figure 3, depicting excellent weld quality. The porosity exhibited in Figure 4 can be attributed to tiny inclusions in the base metal which have been coalesced into larger pores and dropped off as the weld progressed.

The second set of two test assemblies was prepared and welded in accordance with the following criteria:

(1) All surfaces to be involved in the weld (the joint faying surfaces and minimum 1/2 inch back from the joint edge) were abraded to remove all oxides and other foreign materials, followed by solvent cleaning.

(2) Assemblies were preheated to 400°F.

(3) Assemblies were post-weld treated at 400°F.

Post weld NDE (magnetic particle and radiographic) showed that no defects were apparent to the MPI, but that minor indications were present in the radiographs. In an effort to further enhance the interpretation of the radiographs, the test pieces were machined to remove the excess weld material and the parts re-radiographed.

Removal of the excess weld produced radiographs with much better definition of the defects revealed in the original radiographs. The defects were interpreted as incomplete penetration or lack of fusion and some traces of the condition were evident at the root of the weld. Since sectioning would destroy the test pieces, it was decided to attempt to determine whether or not the revealed indications were superficial or not by shallow penetration welding at the root in an effort to remove the defects.

Accordingly, a weld pass was made at the center of the root of each test piece, approximately 0.035 inches deep, and the test pieces radiographed for the third time. Although an improvement was noted, the apparent defects still remained on the radiograph, indicating that the noted discontinuities were buried deeper within the weld metal.

The two test pieces were sectioned starting with a 1-inch section at the center, and alternate 1/2 inch and 1-inch sections taken toward each end. Metallographic examination of the sections showed instances of metal flow discontinuities approximately 3/4 deep into the weld thickness, with the long axis parallel to the path of the welding beam. A typical normal section is shown by Figure 5. The reason for the indications was attributed to:

(1) Residual small porosity inherent in the cast material as supplied as a cause for larger porosity in the welds.

(2) Residual oxides from base metal porosity coalescing with laminar effects and causing intermittent freezing patterns, resulting in droplet-shaped inclusions within the weld metal.

Verification of weld integrity was obtained from tensile specimens tested to the requirements of MIL-STD-418. A report of the results of the tensile test is included in this report (see Table A).

The test results showed adequate yield & tensile strenth. However, the ductility values (%EL & R.A.) were erratic and were typical of a casting exhibiting porosity. It is believed that tests conducted on weldments from forgings would not exhibit this erratic behavior.

Impact tests were made on two typical cross section specimens. The results are shown in Table B of this report, and are typical of as-welded, high-strength, low-alloy steels of the 4340 class. It is interesting to note however, that Weld B shows considerably better properties at -40° than Weld A.

b. Tooling Concepts

Prototype

The design of the prototype tooling was dictated by the two muzzle brakes supplied to EBTEC by the Watervliet Arsenal. The M-B assemblies were not of identical design and consequently, the tooling was made to adopt both. It is not known at this time if the tooling can be used for another type of brake if one should exist.

The muzzle brakes were cut into four pieces consisting of the base, two side webs and the tip plate. The pieces were machined and given ground interfacing surfaces that would be matched together to simulate an assembly fabricated out of forged components.

The tool was designed to locate and hold the four pieces in position while they were first given deep-penetration E.B. tack welds, and then given the final welds. The fixture is designed in two basic components. The arbor provides the axial load for holding the components together, and the motorized cradle provides a mechanism to rotate the part and gives positioning capabilities to reach all welds.

Pictures of the completed tool are shown in Figures 6 and 7. The drawing of the muzzle brake weldment, WTV=D26800, is shown as Figure 8.

Production Tooling

The production tooling design follows the general concept generated in developing the prototype tools, but to a much higher degree of sophistication.

The requirements of a production tool center around fast-loading and handling capabilities, with the tool providing self-locating features. The basic arbor itself will provide these features.

The arbor is basically the heart of the tooling package, and, depending upon what the estimated production quantities are, will determine how many arbor assemblies should be made up. The general concept calls for one arbor to be preloaded while one unit is in the welder being processed, and a third unit is being disassembled. This method would provide for continuous work flow and keep the welding in maximum production.

The experience obtained in the assembly of the two units welded indicates that assembly is best accomplished with the arbor and components in the vertical position. This eliminates the necessity for attempting critical alignments while gravity is working to inhibit joint assemblies.

In the vertical position, the weight of the inserts and muzzle brake top plate provide sufficient force to hold the assembly together, maintain alignment and, yet, permit final adjustments to the alignment before locking is accomplished by tightening the nut on the arbor.

If the assembly were performed on a tiltable trunnion-type mounting baseplate, the arbor could be easily laid over into the horizontal position for assembly into the welding fixture drive cradle.

The cradle assembly is, in concept, similar to the prototype cradle. For production purposes, the cradle is part of the basic work table that would roll in and out of the welding chamber on rails for loading purposes.

The weight of a loaded assembly dictates the need for a heavy duty work handling system to be an integral part of the tooling package. The loaded arbor must be lifted by a hoist and placed on the cradle. The cradle will sit on a roll-out table that will allow the assembly to be rolled into the chamber.

A system designed with three arbors should provide the capability to produce approximately one brake assembly per hour. If additional units are needed, it would be a function of the number of arbors and set-up personnel available.

c. Full Component Welding

Following completion of the welding development, in which it was considered that an optimum welding schedule (See Figure 9) and operator technique was achieved commensurate with the cast material to be welded, preparations were begun to weld the actual muzzle brake components. All components were cleaned by abrasive methods adjacent to the weld joint faying surfaces to remove rust, paint and other foreign materials.

A trial fitup was made of each component to verify fit; see Figures 10 and 11. Grinding of details adjacent to the joint was necessary to achieve acceptable alignments. The assembly fixture was trial-assembled and tested for operation.

With all components and tooling acceptable for fit and operation, parts were final solvent-cleaned and assembly was accomplished. Stages of the assembly are shown in Figures 12 and 13. Views of the assembly and welding tooling at final trials may be seen in Figures 14, 15, and 16.

The assembled components were preheated to 400°F as assembled on the mandrel, transferred into the welding machine and welded according to the pre-established welding schedule and techniques without incident. The final set of two test assemblies was welded in the same manner for verification of the procedures, and proved visually acceptable.

Figures 17 thru 21 show several views of a completed, as-welded component.

Conclusions

Based upon information that the projected production assemblies would be fabricated from forgings rather than castings as demonstrated by the components used in this development, it is estimated that weld quality of the production welds would be improved considerably, since the inherent homogeneity and soundness of the forgings would be much better than castings. There should be no incipient porosity in the material which could coalesce during welding and produce the defects noted in this evaluation, and strength and ductility should also improve.

The tensile test conducted on the forged test specimens show that the welds are of adequate strength since breakage of all tensile specimens occurred in the base material. This also indicates that Heat Affected Zone (HAZ) tempering had no adverse effect on strength. The hardness traverses, however, indicate that the weld strength is attained through a relatively high hardness condition, with resulting reduction in ductility. Since the muzzle brake is subjected to some shock loading, the final assembly should be subjected to the 400°F postweld heat treatment at the time of welding, but be soon after followed by a postweld stress relief/tempering treatment at approximately 1100°F. A common practice presently employed for materials of the type used in the muzzle brake assemblies dictates a postweld heat treatment at 50°F less than the tempering temperature used for the original heat treatment of the assembly details. This treatment would decrease the hardness of the weld to approximately $36R_C$, which is a little harder than the base metal at $32R_C$ and consequently, a little better in both yield and ultimate strength. In addition, the ductility of the weld would be increased to a value quite close to that of the base material, with approximately equivalent resistance to shock loads.

Tests conducted on sections cut from the muzzle brakes revealed are shown in Tables A & B.

The results indicate that in general the electron beam welded cast specimens do not meet the requirements of MIL-B-12253C whereas the electron beam welded forged specimens do.

TENSILE TESTS

TABLE A

Average value of the tensile properties from each weld.

Weld	Y.S. .1% off-set	% El	% RA	UTS
A1	148,800	5.3	11.7	163,900
A2	122,900	2.5	5.5	138,000
B1	140,400	12.3	47.1	155,600
B2	138,900	2.2	4.4	150,400

TABLE B

Average value of the Charpy properties from each weld.

Weld	-40F	Room Temp (75-80F)
A1	12.8 ft-lb	21.0 ft-lb
A2	10.8	19.3
B1	25.8	15.6
B2	22.3	43.4

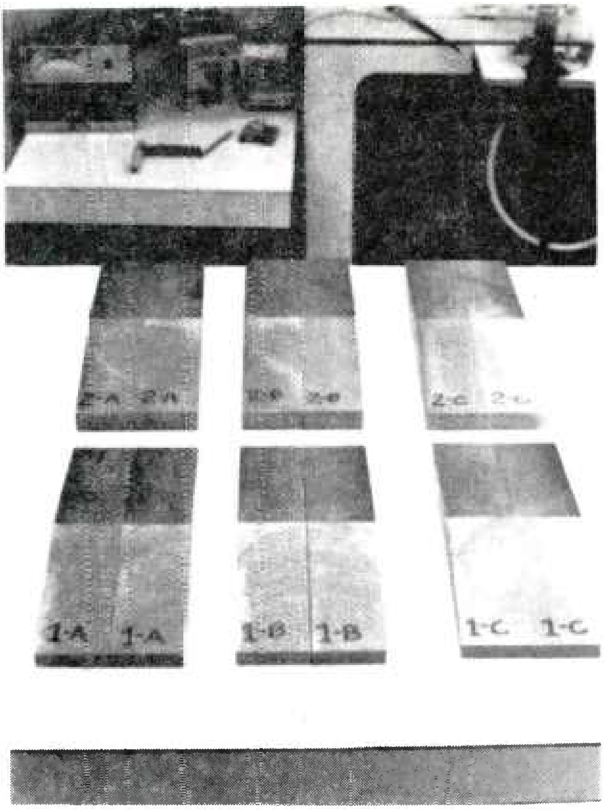


Figure 1. Test samples - top view

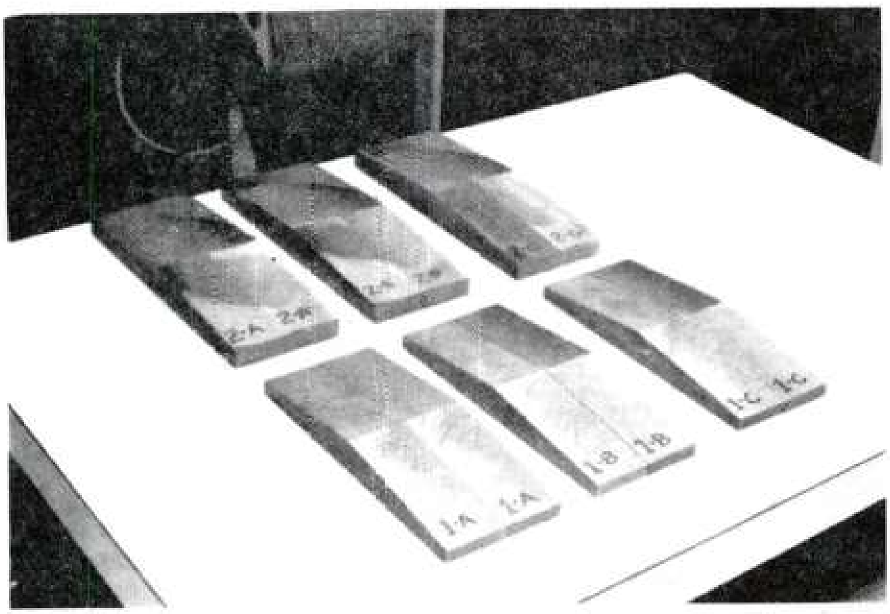


Figure 2. Test samples - top view

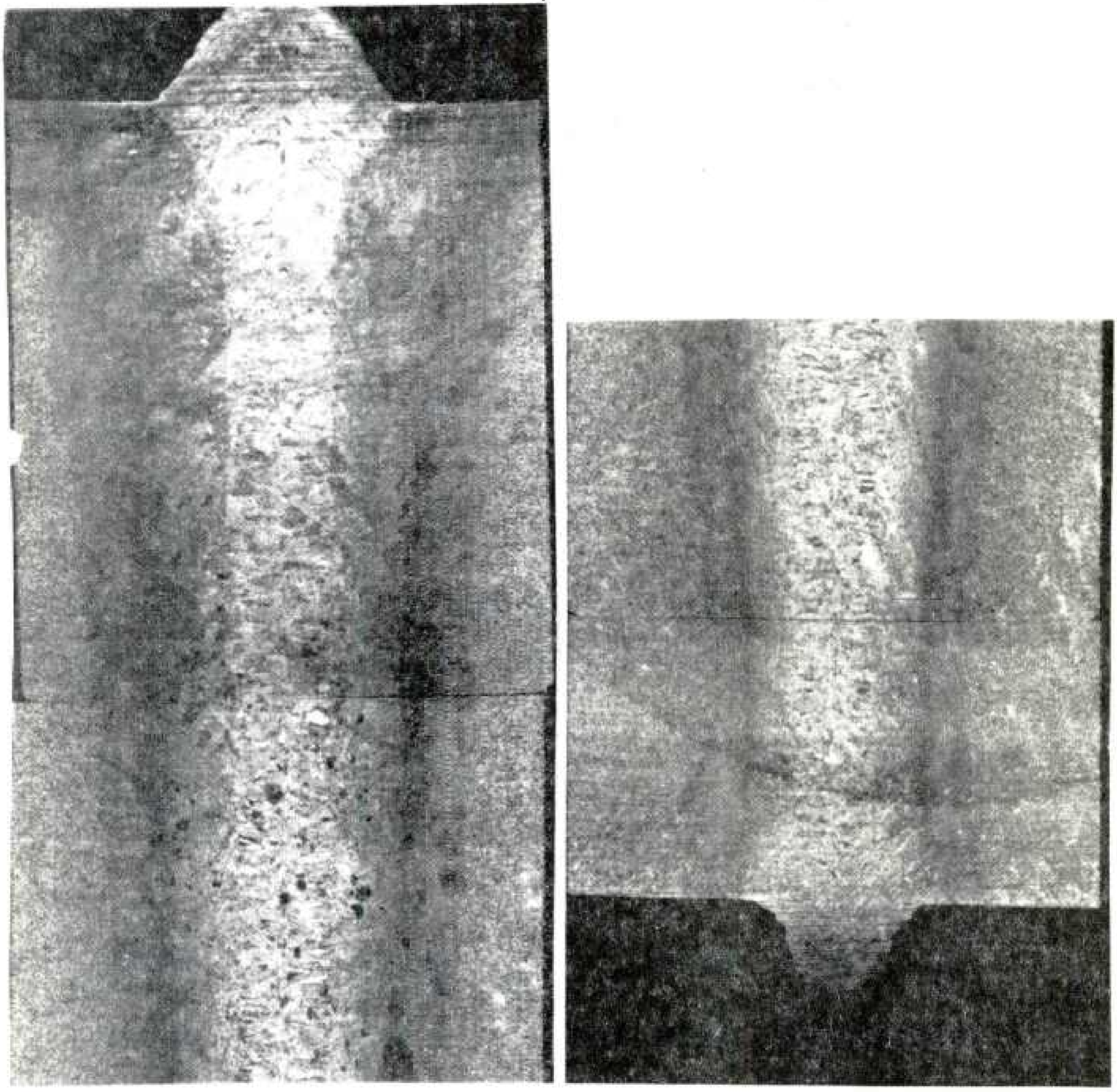


Figure 3. Macrosection - very slight porosity
Section thickness - 13/16 inch

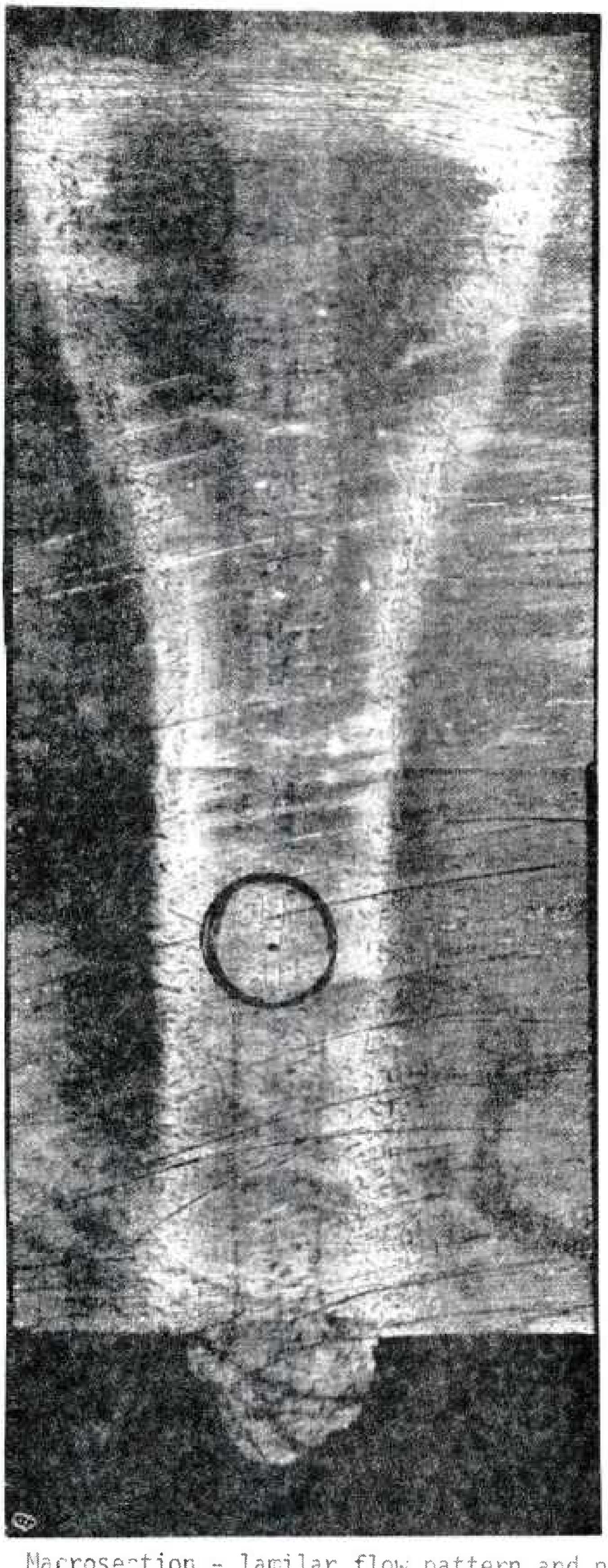


Figure 4. Macrosection - lamilar flow pattern and porosity
Section thickness - 9/16 inch

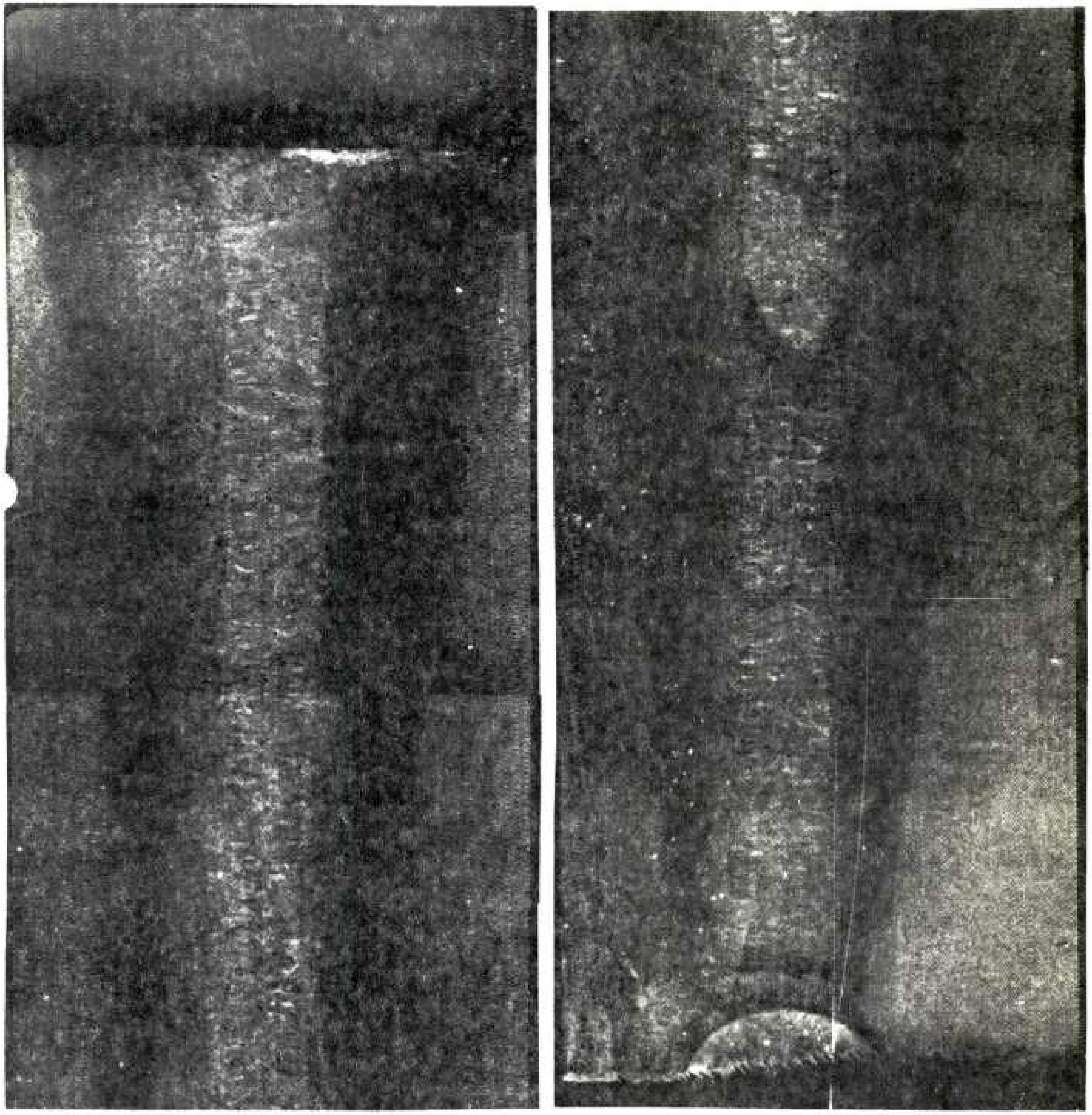


Figure 5. Macrosection - no defects
Section thickness - 1 inch

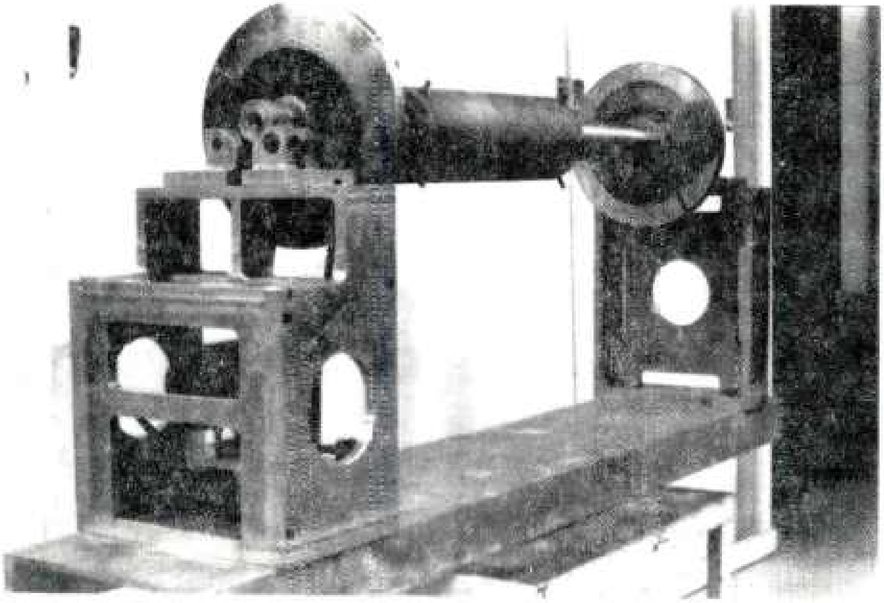


Figure 6. Weld fixture - drive end view

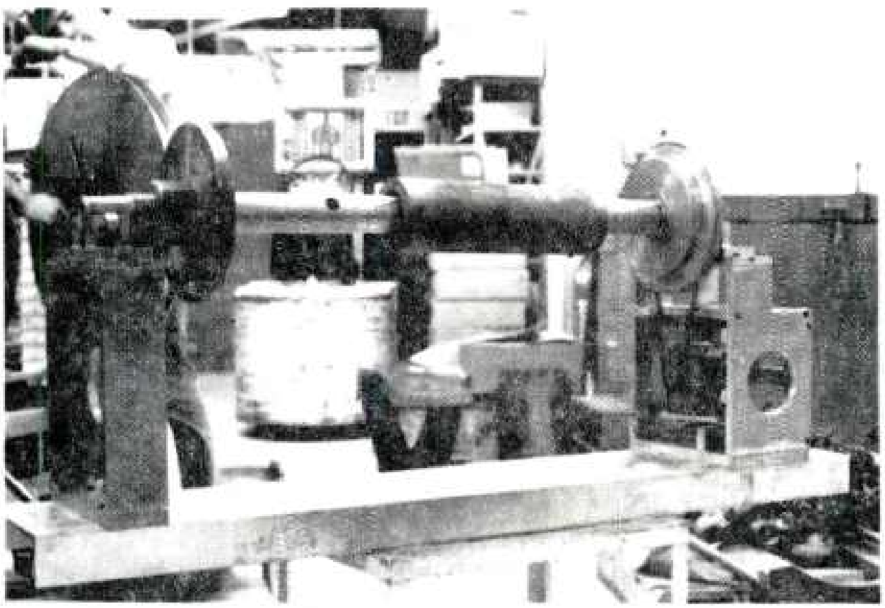


Figure 7. Weld fixture - idler end view

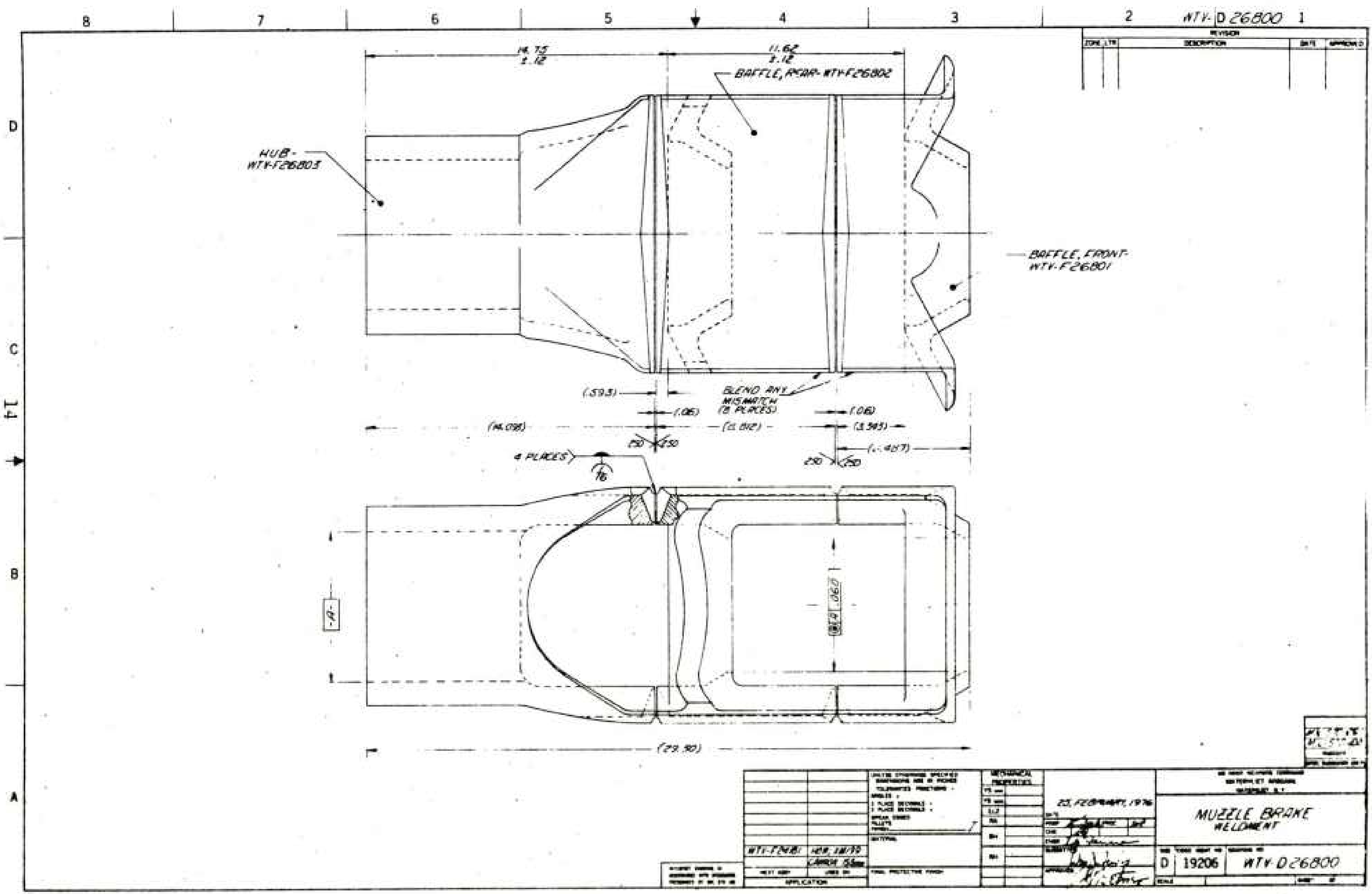


Figure 8. Prototype muzzle brake used in this report

FUSION LABS DIV.

FIGURE 9

HIGH ENERGY ELECTRON BEAM WELDING

WELD SCHEDULE

Customer WATERVLIET

Part No.

Part Name MUZZLE BRAKE

Date 3/15/77

Operator/No. Johnson 1

Machine: Hamilton W3 Sciaky

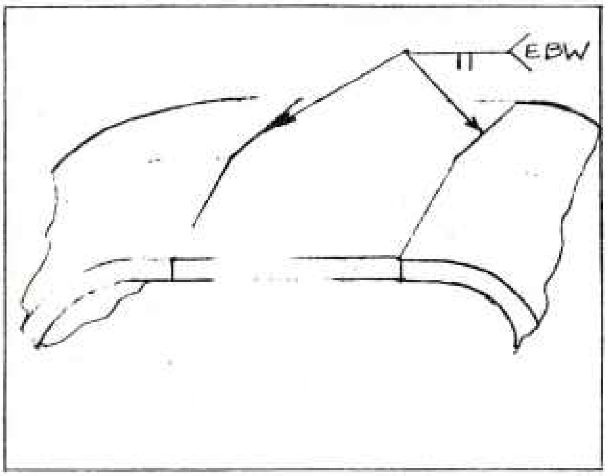
Material Carbon Steel Casting

Fixture Special

Gun Type Ribbon

WELDING PROCEDURES:

Increase and decrease power as thickness varies, set speed in a straight line, not on the angled face of the part.



PENETRATION REQ'D: #1 Weld 100% Interface ______ #2 Weld ______ Interface ______

Type Weld	KV	MA	Deflect	Defocus	Slope Control	Pulsing Freq.	Pulsing Width	Welding Speed Dial	Welding Speed in/min	Welding Speed RPM	Work Dis.	OTHER
Tack Weld	150	10							15			
Weld # 1	150	30 to 45	---	---	---				15			
Weld # 2												
Clean Up	150	10 to 15							15			

#	Date	Operator	FLJ #	QTY	Comments
1					
2					
3					
4					
5					
6					
7					
8					

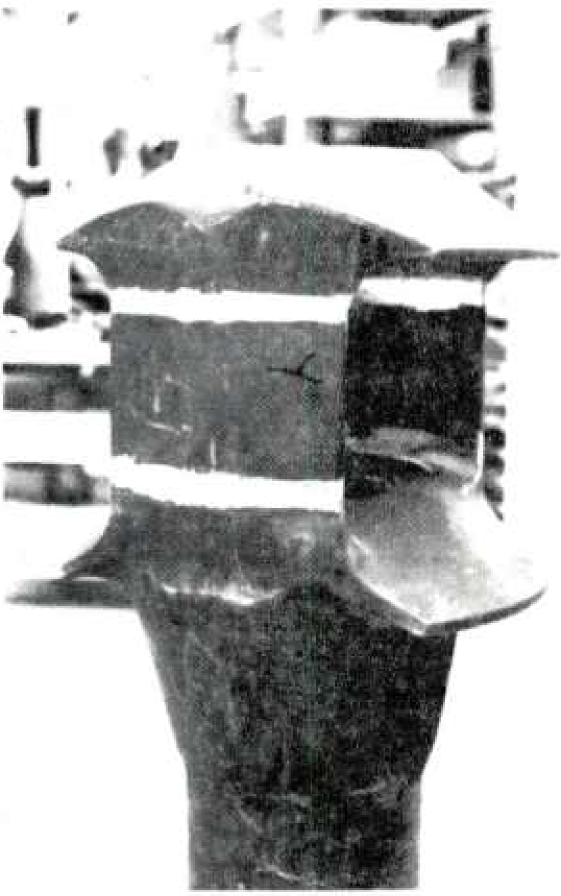


Figure 10. Trial fitup assy. - one side

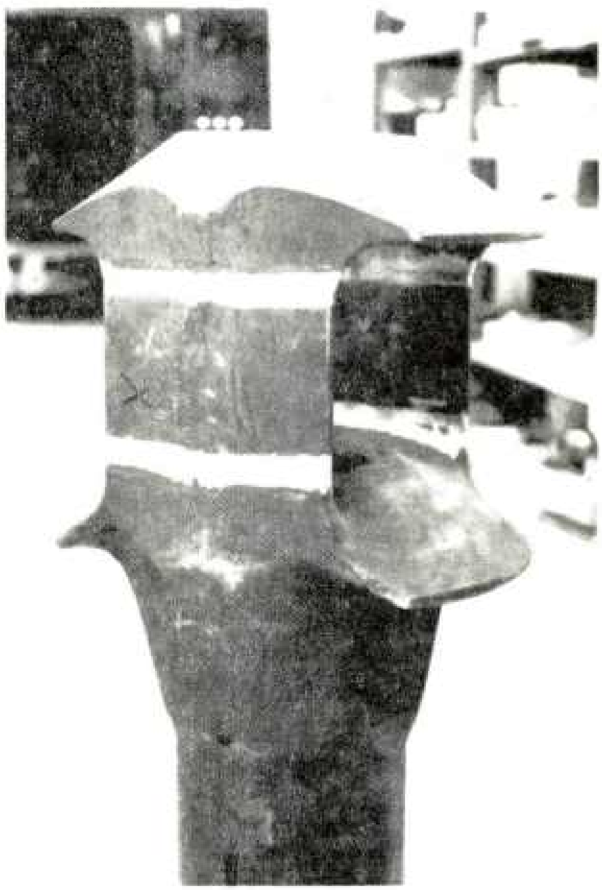


Figure 11. Trial fitup assy. - second side

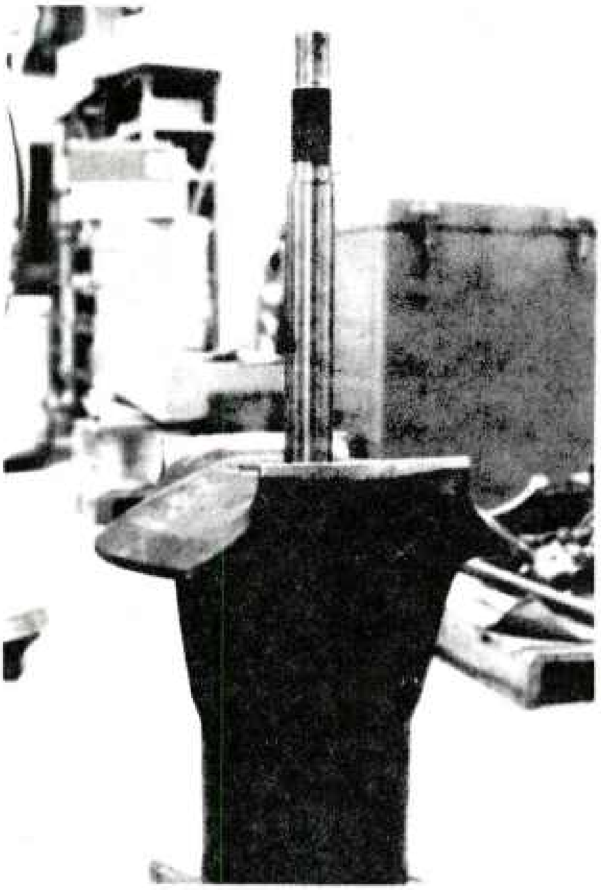


Figure 12. Muzzle brake assy - start

Figure 13. Muzzle brake assy - lock

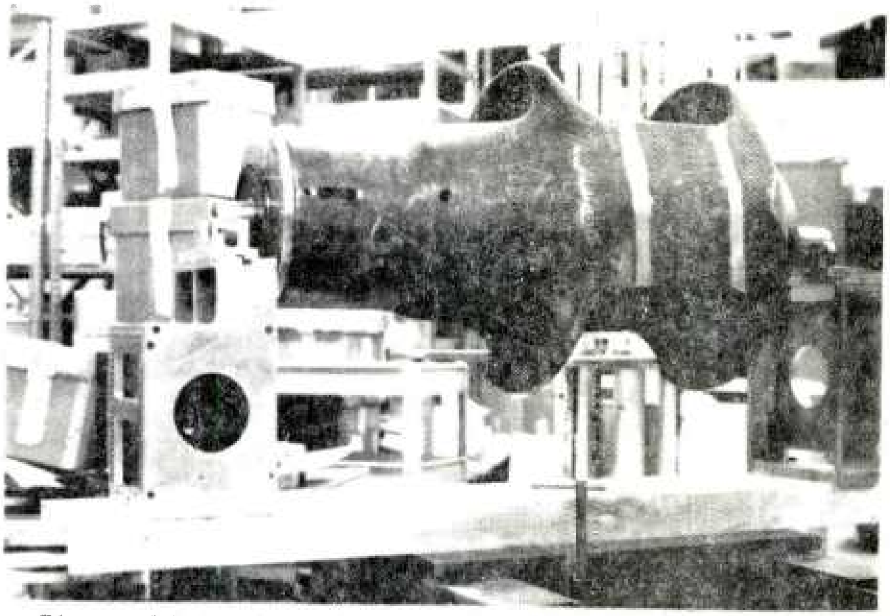


Figure 14. Muzzle brake assembly - in weld fixture

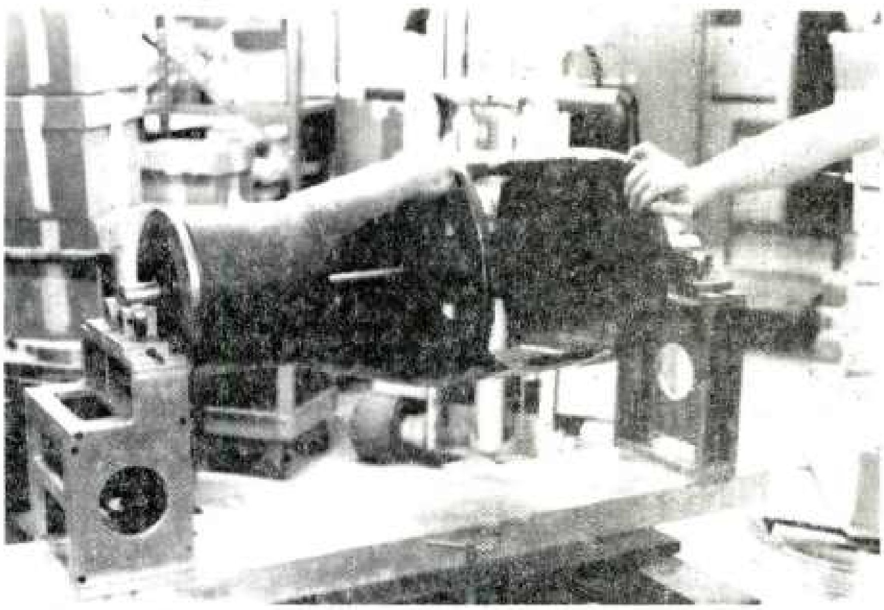


Figure 15. Muzzle brake assembly - in weld fixture

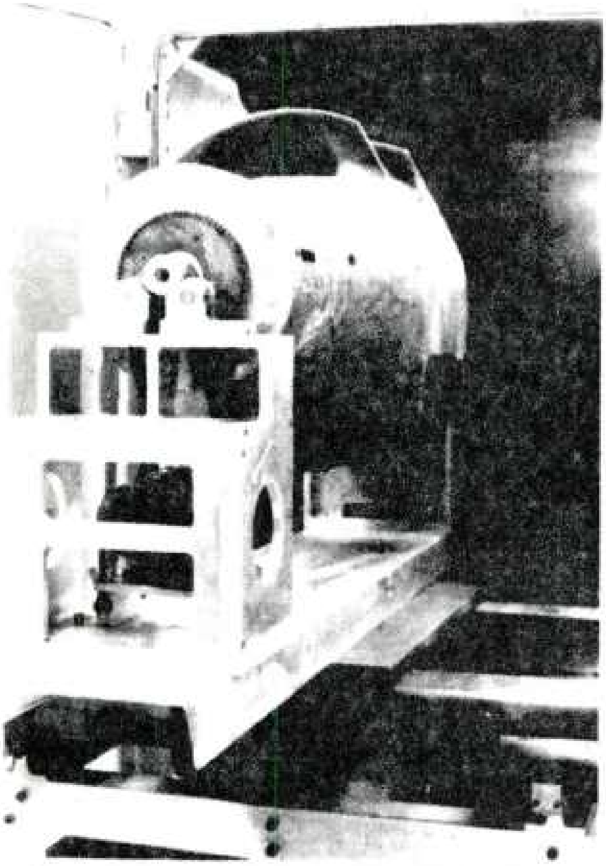


Figure 16. Assembly in weld fixture driven end

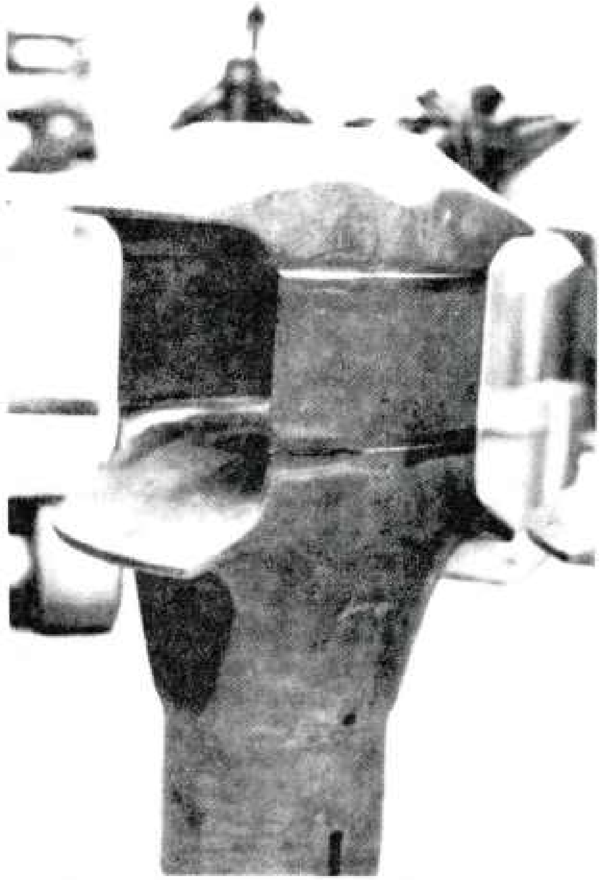


Figure 17. Welded muzzle brake assembly

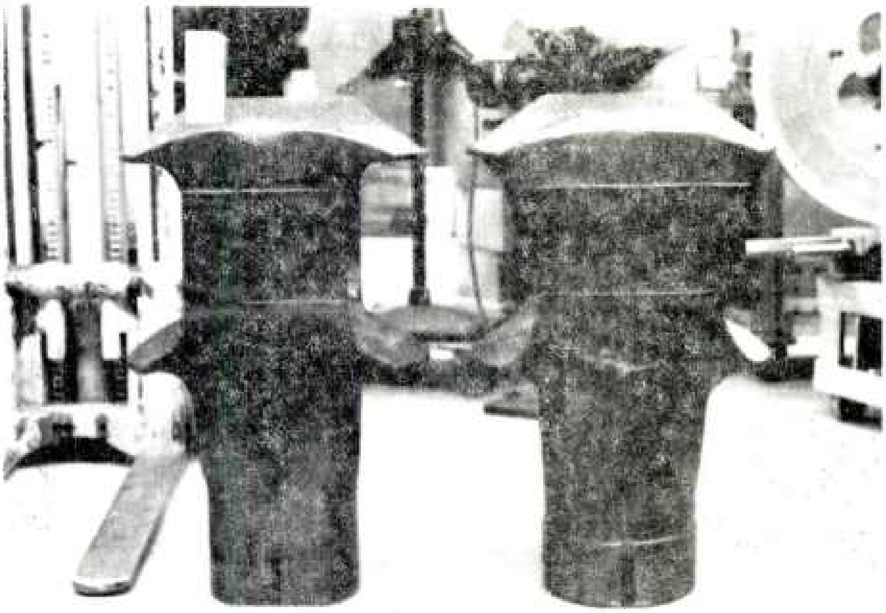


Figure 18. Welded muzzle brake assemblies - both types

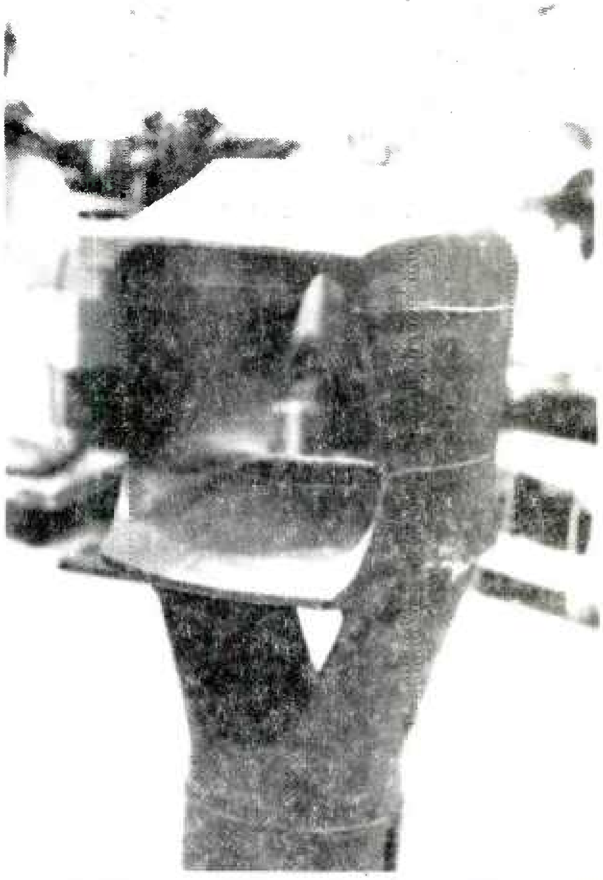


Figure 19. Welded muzzle brake assembly - second type

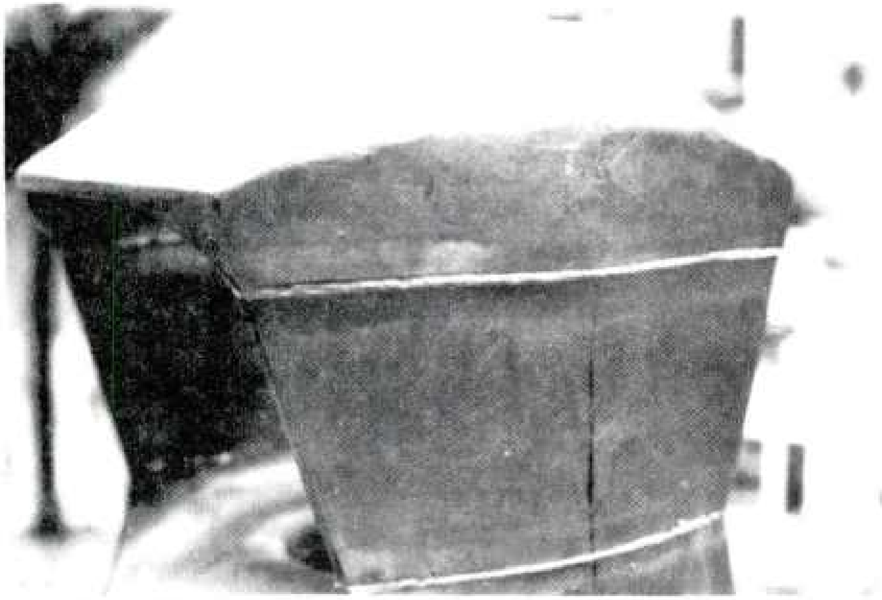
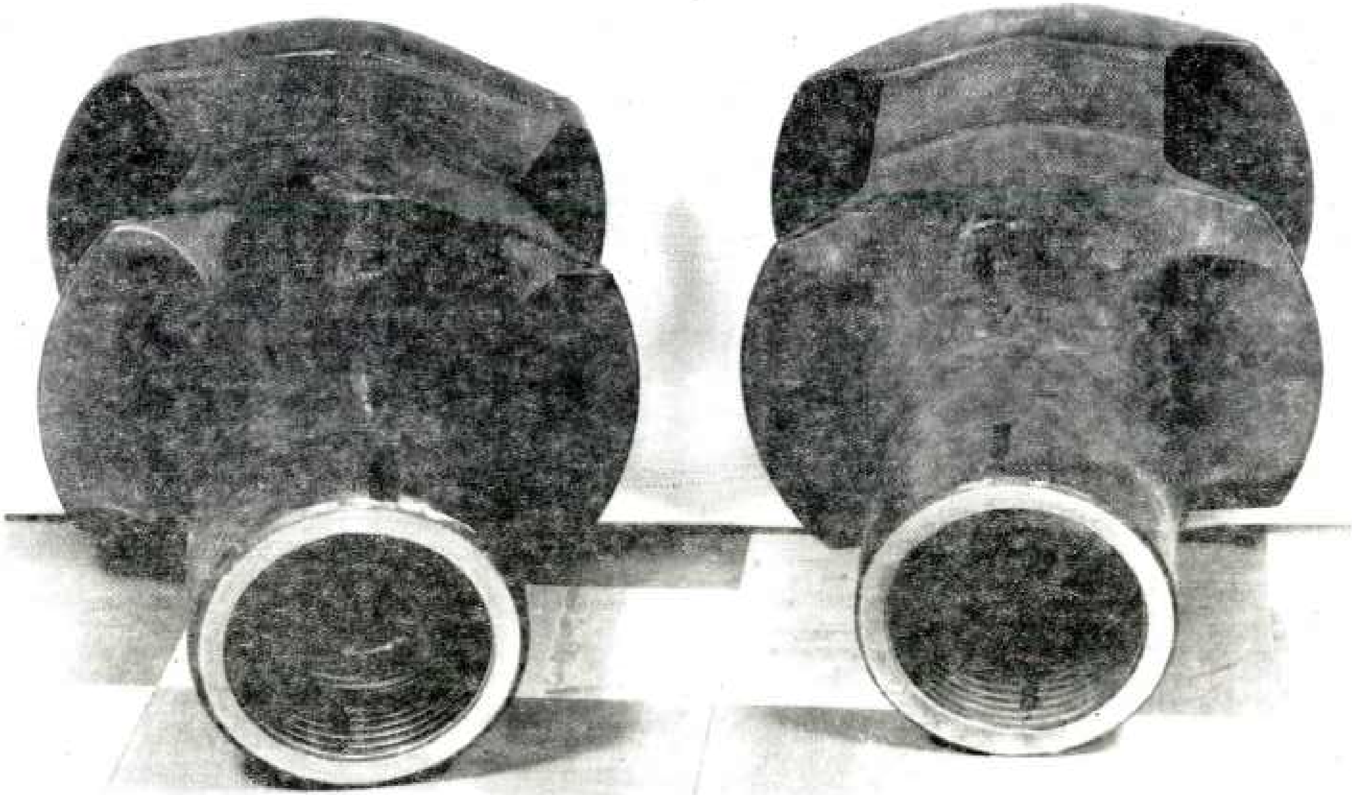


Figure 20. Close up of welds - typical muzzle brake assembly



Muzzle Brake A

Muzzle Brake B

Figure 21

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COMMANDER US ARMY MATERIALS & MECHANICS RESEARCH CENTER ATTN: TECH LIB -DRXMR-PL WATERTOWN, MASS 02172	2

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.